Patterns of the noise level change at different speeds for mixed traffic flows

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Abstract. The study describes the problems of determining the normative levels of traffic noise on city main streets. The main statements and preliminary laws that are taken into account when determining the acoustic characteristics of the urban environment in the current building regulations are considered. It was established that the main factor that determines the acoustic load on city streets is the type of covering. The dynamics of the level of traffic noise of mixed flows, taking into account different types of coverage at different speed regimes, are also determined. The obtained results partially differ from the calculated values, and therefore are relevant for the development of modern norms and rules for the calculation of traffic noise on city highways.

1 Problem statement

Modern large cities face a significant number of environmental problems caused by transport oversaturation, both private and public. Along with the main problem - harmful emissions into the atmosphere, the issue of acoustic load on arterial city streets is acute. The study of these issues is partially considered in works [1-2].

In the process of searching for mutual placement of residential areas and transport infrastructure optimal solutions, the question of determining the current and prospective levels of traffic noise from arterial streets is acute. Currently, standards such as SNIP II -12-77 [3] and DSTU-N.B.V. 1.1-33:2013 [4] are used. Although the last standard is relatively new, its main provisions are based on the results of research in the 50s and 60s years of the last century. During this time, the dynamic performance of vehicles, noise insulation materials, chassis, and transmission designs of cars have changed significantly, and the general concept of internal combustion engines both with the new types of car tires and acoustic efficiency has improved.

In many cases, the characteristics of transport and its infrastructure in these built-up areas are specific, which leads to a discrepancy between the design and actual levels of noise discomfort. This problem is often ignored, because the value of land within the urban space is extremely high, and it is economically unprofitable to foresee additional territorial gaps between the roadway and the first line of development.

First of all, this refers to a common dilemma in the development of detailed plans territory, when urban planning architects make decisions based on current norms and rules, acting within the limits of current legislation, but do not conduct consultations with transport engineers and scientists, whose opinion may differ from the adopted design solutions.

A situation arises that leads to an overtime level of noise in areas of residential development, when it is physically impossible to apply noise protection structures or other measures.

In such conditions, there is a need for additional field studies that would help determine the dependence of noise level change at different speeds of mixed traffic flows. This feature also considers the type of road surface.

The obtained results should be compared with the calculated ones since it is quite important to determine the discrepancies between the recommendations of standards and norms and the real situation in the urban environment.

2 Research methodology

At this time, in Ukraine, either the nomogram recommended by the source [3] or the calculation formula (1) from the source [4] is used to determine the levels of traffic noise ($L_{eq}$).

$$L_{eq}=44+0,26 V + 10 \lg (N_{wt}/V_{an}) + \Delta L_{korr} + \Delta L_{sur}$$ (1)
In this equation, variable \( V \) means average traffic flow speed, variables \( \frac{N_{\text{un}}}{V_{\text{un}}} \) are describing united traffic intensity and speed. Corrections \( AL_{\text{sur}} \) and \( AL_{\text{sl}} \) are responsible for noise increasing by surface and slope. General noise levels

### Table 1. Noise levels according to DSTU-N.B.V. 1.1-33:2013.

<table>
<thead>
<tr>
<th>Street type</th>
<th>Number of lanes</th>
<th>Noise level, dBA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial street (general city significance)</td>
<td>6</td>
<td>82</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>81</td>
</tr>
<tr>
<td>Arterial street (district significance)</td>
<td>4</td>
<td>79</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>78</td>
</tr>
<tr>
<td>Residential streets</td>
<td>2</td>
<td>70</td>
</tr>
<tr>
<td>Industrial streets</td>
<td>2</td>
<td>81</td>
</tr>
</tbody>
</table>

However, numbers from the Table 1 highlight upper edges of noise level on different types of streets. But, in the same standard, noise level can be calculated and the results can reach ridiculous difference from the table.

According to such calculations, equivalent noise level on arterial streets may increase up to 78-81 dBA. In the same standard, road surface impact may be up to 5 dBA. Taking into account the nomogram [3], average noise level on arterial streets is between 70-75 dBA. Different interpretations and methods of acoustic calculations are forcing to run additional traffic surveys which can help to appreciate some valuable factors of noise pollution by field studies. The important point is that traffic speed impact and type of road surface must be characterized as key factors of acoustical discomfort on arterial streets. In this study it is necessary to compare the results of field research and calculations from [3-4] with the same input data.

Field research were provided on district significance arterial streets, considering those traffic characteristics:

- number of lanes (constant) – 2 (1 on each direction);
- traffic volume (constant) – 450-500 vehicles per hour;
- traffic speed (variable) – 10-50 km/h;
- traffic composition (variable) – 80% cars plus 20% cargo and public transport or 100% cars;
- road surface (variable) – cobblestones and asphalt;
- slope (constant) – less than 1%;
- environment temperature (constant) – 20-23°C;
- wind speed (constant) – 2-4 m/s.

Survey was running on different street types with another road surface composition. Typical street view for these types described on Fig. 1 and 2.

This street type is characterized by various traffic flow during different periods of the day (above 650 and 300 vehicles per hour in peak and non-peak periods). The cobblestones road surface is in tolerable condition, however, this environment is typical for streets, that are located near the old town center.

The quality of cobblestones surface is also a significant factor, which can make noise level increasing. Nowadays, most streets, that are included to 1-st type, are modernized and the surface quality is typical for such road constructions. Streets with unsatisfactory cobblestones placing were not researched.

Environment of these streets is typical for most cities in Ukraine. Such sections are characterized by medium number of vehicles per hour (350-550) and wide variety of momentum speeds. Also, the traffic composition on such streets is rather constant, but in morning hours there is a big number of city logistic vehicles.

For more clarity, there momentum speed distribution by the intensity of traffic flow 370-460 vehicles per hour was also discovered. The results for the 1-st street type are shown as normal distribution diagram on the Fig 3.

Survey shows that mean of the sample is 26.8 km/h and the standard deviation like 9.5 km/h. This numbers are useful for exploring noise level change by different
speed modes. The results for 2-nd street type are described on the Fig. 4.

![Fig. 4. Momentum speed distribution on the 2-st street type.](image)

Results can be explained by the driven manners of the vehicles, as cobblestones is hard surface, that can divide drivers by groups. One part of them use SUV’s or another vehicle types with soft suspension, that allows to drive on higher speeds, another drivers group prefect to ride slowly on such streets. However, mean of this sample is about 23 km/h and the standard deviation is equal to previous research.

Noise measurements were carried out using a Flus ET-956 USB Sound Level Meter device [5] that has proven itself well in previous studies [6]. The measurement technique consisted in recording the noise of mixed and homogeneous vehicle groups, moving with different speeds at a distance of 1.5 m from the axis of the near lane.

For a complete analysis of the survey, the results of measurements on different types of road surfaces during the movement of traffic flows of different compositions were worked out. Next, the obtained results are presented as graphic and analytical dependencies.

3 Survey results

The first stage of research was carried out on the main street of district importance, which has a road surface made of cobblestones (1-st street type). Fig. 5 and 6 compare the change in noise level depending on the speed of movement for mixed and homogeneous (vehicle) traffic flow, respectively.

The results of field studies are significantly different from the calculations because, at speeds greater than 30 km/h, the noise level increases significantly and amounts to 75-80 dBA. It is also worth noting that with the increase in the speed of the traffic flow, this difference increases and can amount to 15-20%, which indicates an insufficient amount of correction for the noise level in the presence of a paved road surface.

Somewhat different are the results of the measurements that were carried out for the traffic flow, which consisted of 100% passenger cars. In this case, the results of the calculations do not differ significantly among themselves, however, the data of field studies again indicate higher values of noise levels when moving on cobblestones.

![Fig. 5. Dependence of noise level change on the 1-st street type, considering various speeds of mixed traffic.](image)

![Fig. 6. Dependence of noise level change on the 1-st street type, considering various speeds of homogenous traffic.](image)

The results of the measurements differ significantly from the calculated values when reaching speeds greater than 25 km/h. If the DSTU and SNIP standards determine the average noise level at a speed of 50 km/h is equal to 71 dBA, then in practice, it is 80 dBA, which indicates a critical discrepancy between the results.

Fig. 7 and 8 show similar dependencies during traffic flow on an asphalt concrete surface.

On this type of coating, the situation is radically different. If the calculations according to the current DSTU show underestimated results, then the data of field studies and the results obtained according to the methodology of the SNIP almost coincide and correspond to a noise level of 70-71 dBA at speeds of 45-50 km/h. It is also worth noting that the difference between the results of field tests for cobblestones (Fig. 5) and asphalt is 10 df
dBA, which is significantly higher than the number of corrections proposed by the standards.

The results of noise level measurements on an asphalt concrete surface for a homogeneous flow do not have critical discrepancies with the calculations. Thus, the maximum noise level (at a speed of 50 km/h) according to calculations is 65-66 dBA, and according to the results of research - 68 dBA, which indicates a small error.

The obtained results make it possible to carry out an additional thorough analysis of the regularity of changes in the noise level depending on the speed and coverage, and especially, the influence of the traffic flow composition on this dependence.

It is known that according to the calculation methods, there are coefficients and corrections that take into account the type of coating and the composition of the flow. However, based on previously obtained research results, it can be concluded that the values of these corrections may differ among themselves. The impact of the pavement on the noise level may vary depending on the number of trucks and buses in the traffic. At the same time, the value of the correction, which takes into account the composition of the flow, may also be different depending on the type of road surface.

In Fig. 9, the dependence of the change in the difference in the noise level between a mixed and homogeneous traffic flow at different speeds is given. The difference between noise levels of mixed and homogenous traffic is calculated comparatively to lower (100% car) limit. The value of these calculations is to demonstrate the effect of traffic flow composition on different road surfaces. This becomes possible by comparing two graphs that illustrate this phenomenon at different speeds.

The obtained results indicate an interesting trend observed in the movement of traffic flows on different road surfaces.

If we talk about the street of the second type with an asphalt concrete surface, the difference in noise levels between homogeneous and mixed traffic flow is significant. At minimum speeds (10-15 km/h), the difference is already 5.5%, at average speeds it reaches 7-7.5%, and at the maximum permissible flow speed, these values differ by more than 9%.

This shows that when driving on an asphalt concrete surface, the type of transmission, as well as the type and volume of the engine, together with the features of the exhaust gas release system, play a major role. The weight of these factors increases proportionally with movement speed.

A completely different situation is observed on the first type of streets, which are paved with cobblestones. The difference in noise level between mixed and homogeneous (100% passenger cars) traffic is less noticeable and varies with speed within statistical error.

This difference ranges from 2.8 to 3.5%, regardless of the vehicle's speed. This shows that the composition of the
traffic flow does not play a significant role in the acoustic load on this type of streets. This is explained by the fact that the general traffic noise is quite high and it suppresses other factors influencing its level. Thus, we can observe that the noise generated by the contact of the wheels and the suspension elements is so high that the operation of the engine, exhaust system and transmission does not affect its overall level.

Such results indicate the need to use a fundamentally new approach in determining the existing and prospective noise levels on city main streets of district importance. This takes into account both the composition of the traffic flow and its impact on the overall acoustic load, as well as the magnitude of this impact on different types of road surfaces. It is also worth noting that the mixed traffic flow in this work has a distribution of 80/20% cars to trucks and buses.

The difference between the results of field studies and calculated values is quite significant, although both rarely reach the noise level values indicated in Table 1. It is important to note that the amount of correction for the increase in noise level due to the change in road surface does not depend on the traffic speed, composition of the flow and its intensity. This is not a completely correct way to determine the calculated noise level, since the intensity of traffic, the composition of the flow, and especially its speed, are factors that change the magnitude of their impact on different types of pavement. This especially applies to asphalt concrete.

Table 2 shows the difference in corrections for the presence of cobblestones in various regulatory documents and according to the results of field studies. It is worth noting that in DSTU the magnitude of this correction does not depend on the speed of movement, although in SNIP this dependence is present. Also, the traffic intensity and composition of the flow are not taken into account in the regulations (in the results of field studies, 20% of trucks and buses and approximately 400 cars/hour are provided for).

<table>
<thead>
<tr>
<th>Traffic speed, km/h</th>
<th>SNIP II-12-77 Correction, dBA</th>
<th>DSTU-N.B.V. 1.1-33:2013 Correction, dBA</th>
<th>Survey results</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>+1</td>
<td>+5</td>
<td>+4</td>
</tr>
<tr>
<td>20</td>
<td>+2</td>
<td>+5</td>
<td>+5</td>
</tr>
<tr>
<td>30</td>
<td>+3</td>
<td>+7</td>
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<tr>
<td>40</td>
<td>+4</td>
<td>+10</td>
<td>+10</td>
</tr>
<tr>
<td>50</td>
<td>+5</td>
<td>+12</td>
<td>+12</td>
</tr>
</tbody>
</table>

Therefore, the amount of corrections to take into account the cobblestone road surface according to SNIP can be from 1 to 3 dBA, which according to the results of field studies is insufficient, although, in this document, it varies in relation to the speed of the traffic flow.

As for the current standards of the DSTU, they do not provide for changes in the value of the correction for the type of surface depending on movement speed. This factor is the point when calculating the overall noise level according to formula 1. The correction itself is 5 dBA, which, according to the results of field studies, corresponds to traffic flow speeds of 10-20 km/h.

Compared to these values, the results of natural studies look completely different. According to them, the average value of the correction for traffic flows, which consist of 100% of passenger cars, can be from 4 to 12 dBA.

The minimum correction values are observed at speeds of 10-20 km/h, at a speed of 30 km/h it is already 7 dBA, and for 50 km/h – 12 dBA, which significantly affects the overall calculation of the noise level.

Based on this, it is worth noting that the calculation methods according to the DSTU (in force) are quite generalized and do not differ significantly from the previous normative documents. Taking into account the fact that at this time the dynamic and ecological characteristics of vehicles and their components are a level higher than at the time of the development of the norms, the noise characteristics of the flow differ for the better. However, the influence of the quality of the road surface is not fully taken into account, which can lead to discrepancies between the design and actual values of the level of noise discomfort in rural areas. And this means that when developing urban planning documentation, sanitary gaps from residential buildings to main streets of district significance may be smaller than is actually necessary, since the real noise level will not be completely eliminated due to such a gap.

4 Conclusions

The work considers modern problems of territory planning taking into account traffic noise. It has been established that at the stage of designing residential buildings, architects and engineers are guided only by the standards and calculation methods that are recommended for such types of design work. However, these same standards are relatively outdated and do not take into account changes in the technical parameters of vehicles and also do not fully provide weight to such factors of impact on traffic noise as traffic speed and type of pavement.

The research was carried out on sections of main streets of district importance, where relatively the same traffic intensity, flow composition and speed regime are observed.

Field studies conducted in these locations showed a significant difference between calculated noise levels and real values. Thus, when driving on cobblestone streets, the difference between the calculated noise values and the measurement results is 7% (increasing according to the measurement data) at average flow speeds and up to 14% at the maximum permissible speeds (40-45 km/h).

It is important that, according to the results of field studies, the influence of traffic flow composition on the noise level is different. When moving on cobblestones, the difference between a mixed traffic flow and a
homogeneous one does not exceed 3.5%, regardless of the speed of movement. And such figures indicate that when predicting the level of noise on streets with a road surface made of cobblestones, this factor is not decisive, since the contact of vehicle wheels with the road surface produces the most noise.

Observing the movement on streets with an asphalt concrete surface, the composition of the traffic flow at different speeds is of decisive importance in the calculation of the noise level. The difference between homogeneous and mixed (20% freight and buses) traffic flow can grow up to 9% at speeds 45-50 km/h. This also indicates that the method of calculating traffic noise, which is available in the regulatory documentation, does not fully take into account the composition of the flow and speed, since these two factors in the calculation formulas do not significantly strengthen the result. Meanwhile, it is also necessary to take the fact that the flow speed in urban conditions on two-lane streets has a unimodal distribution, so it is not always correct to take into account separate speed regimes for different vehicles. And the composition of the flow is an forcing factor in noise level increase when the speed of the flow rises.

Comparing the research results with the normative methods of calculating the noise level, it is also worth noting that the amounts of corrections for the presence of cobblestone road surfaces may be insufficient, which, in turn, may lead to additional problems already after the implementation of residential development projects in cities.

According to normative calculation methods, the value of the correction for the type of road surface does not exceed 5 dBA. At the same time, according to measurement data, this correction can be from 4 to 12 dBA depending on the flow speed.

The results of the research in this work fully and completely confirm the fact that when planning the areas of residential development, which are adjacent to the main streets of district importance, it is necessary, first of all, to be guided by analytical materials regarding the determination of noise levels for the future. At the same time, the value of the levels of possible noise discomfort can be used as a lower limit in cases where the recommendations of transport engineers and scientists do not conflict with planning decisions.

This will contribute to a clearer definition of regulatory distances from the carriageway of city streets to areas of residential development, or will be a basis for predicting additional noise protection measures at the stage of developing detailed plans of the territory.

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